Hurricane & ReCyclone® Systems
ADVANCED CYCLONE SYSTEMS
A company exclusively dedicated to the development of optimized cyclones

VISION Leading the conception and distribution of cyclone systems on a global level, contributing to a healthier environment and to the growth of client’s competitiveness, maintaining high standards of service and quality with qualified and motivated human resources.

MISSION Maximizing particle capture with cyclones, freeing the client from the costs and problems of bag filters.
ACS has grown to become a worldwide reference in cyclones in 8 years of existence

- Established in **May 2008** by Pedro Araújo and Romualdo Salcedo, supported by the CoHitec program and promoted by COTEC
- Backed by **Espírito Santo Ventures** in 2009
- Headquarters in Porto, Portugal, with **18 employees** today
- Unique scientific knowledge in cyclone design optimization and particle agglomeration modeling (PACyc) in partnership with the **Engineering Faculty of Porto (FEUP)** where it runs a pilot system for R&D.
- Has become a worldwide reference in cyclones, with over **250 successful installations in 36 countries in 9 years**
- Scalable, profitable business model based on:
  - Clearly **differentiated** market position
  - Optimized cyclone design and **accurate efficiency prediction capabilities**
  - **Validated right** first time installation
  - Introducing **standardized solutions** to meet a wide range of client industry applications

www.advancedcyclonesystems.com
ADVANCED CYCLONE SYSTEMS

Provider of high-performance gas/solid separation at a lower total cost of ownership

By its superior efficiency, ACS cyclones displace other more maintenance demanding technologies, such as Bag Filters, or much more expensive ones, such as ESPs
PROVEN TECHNOLOGY, GLOBAL FOOTPRINT ACS HAS INSTALLED PRODUCTS IN 36 COUNTRIES

Number of installations per country

North, Central & South America  Europe  Africa  Asia  Oceania

6/6/2019  www.advancedcyclonesystems.com
Filtration and Separation Technologies

Two main market needs

**POWDER RECOVERY**
Serious Economic Added Value

- 60% of the world chemical related industries handle products in the fine powder form.
- Significant shares also apply to the Pharmaceutical, Food Ingredients, and Mineral industries, among others.
- Virtually all powder processing industries need gas-solid separation.
- Many are actively seeking to optimize the yield of their processes and reduce powder losses.

**EMISSION CONTROL**
Environmental Improvement

- Increasingly strict Particulate Matter (PM) emission limits are being enforced worldwide. Poor air quality is the number 1 environmental cause of premature death in the EU.*
- Majority of combustion processes are associated with PM Emissions. Cleaning hot gases is mandatory for heat recovery and to improve plant efficiency.
- Many other processes in large industrial plants are sources of PM: (Steel, Cement, Paper, Glass…etc.).

*www.advancedcyclonesystems.com
HOW CAN ACS TECHNOLOGY HELP YOU WITH A MORE EFFICIENT POWDER COLLECTION?
DESPITE NUMEROUS ADVANTAGES, REGULAR CYCLONES HAVE LOW EFFICIENCY

Reverse flow cyclones benefits:

- Robust
- Absence of maintenance
- No pressure problems
- No moving parts
- Work on a dry basis
- No temperature restrictions
- No electrostatic components
- No filters

Wide Industrial Application

Problem: Low efficiency for particles < 10µm*

*1µm = 1/1000mm

Typically, traditional “non optimized” cyclones have to be complemented with other separators due to their low efficiency.

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EXAMPLE OF DIFFERENT TYPES AND SIZES OF CYCLONES
**Sources & Problems**

### Usual sources of PM emissions:

<table>
<thead>
<tr>
<th>COMBUSTION PROCESSES</th>
<th>DRYING PROCESSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boilers, Furnaces, Incinerators, Gasifiers</td>
<td>Rotary Dryers, Vertical Dryers</td>
</tr>
<tr>
<td><strong>Biomass Boilers</strong></td>
<td></td>
</tr>
<tr>
<td>District water heating</td>
<td></td>
</tr>
<tr>
<td>Heat production in industry</td>
<td></td>
</tr>
<tr>
<td>Steam production in industry</td>
<td></td>
</tr>
<tr>
<td><strong>Biomass Dryers</strong></td>
<td></td>
</tr>
<tr>
<td>Pellet manufacturing</td>
<td></td>
</tr>
<tr>
<td>Particle board manufacturing</td>
<td></td>
</tr>
</tbody>
</table>

### Problems of existing solutions:

- **Bag Filters**
  - Critical operational problems & high maintenance costs at high temperature or moisture.

- **Electrofilters (ESPs)**
  - High investment cost & restricted applicability

- **Wet Venturi Scubbers**
  - High operational costs and production of secondary wet pollution with associated treatment costs.

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**Need for an affordable, efficient and problem free technology!**

[www.advancedcyclonesystems.com](http://www.advancedcyclonesystems.com)
THE SOLUTION: NEW & MORE EFFECTIVE CYCLONES!
THE SOLUTION: MUCH MORE EFFICIENT CYCLONES

How do we improve cyclone efficiency?

- Difficult to model cyclone separation dynamics
- Cyclones are usually designed empirically or, less often, according to models which can be found in the literature that do not consider the inter-particle agglomeration inside the cyclone
- ACS has developed its own unique model for cyclone efficiency prediction which takes into account agglomeration (clustering) in turbulent flow fields

- ACS can rapidly generate millions of virtual prototypes and, through numerical optimization, select the best geometry to each given cyclone application
- This takes into consideration several economical and operational constraints, such as size, pressure loss or manufacturing cost.
- The optimization approach has resulted in multiple cyclone patents

- ACS has further increased cyclone efficiency with unique patented recirculation systems, using pure mechanical or electrostatic dynamics (ReCyclone®)

ACS’ competitive advantage is sustained by its unique ability to accurately estimate, and consequently guarantee a requested efficiency, resulting in better cyclones optimized for a specific application.

www.advancedcyclonesystems.com
UNDERSTANDING HOW CYCLONES WORK
Developing the best theory for cyclone collection

Predicting particle agglomeration in cyclones (PACyc)

Trajectories
Agglomerate Formation

www.advancedcyclonesystems.com
UNDERSTANDING HOW CYCLONES WORK

Several constrains are imposed on design

Wide range of operating conditions:
- $85^\circ\text{C} < T < 120^\circ\text{C}$ (negative $T$ for cryogenic micronizers)
- $\ldots \text{mg/Nm}^3 < C_{\text{in}} < \ldots \text{kg/Nm}^3$
- $\ldots 25 \text{Nm}^3/\text{h} < Q < \ldots 150,000 \text{Nm}^3/\text{h}$ (?)

Type of product:
- solid dispersions, inhalable, injectable, microcapsules, tablets’ waste recovery, …
- wide range of densities (non-porous, porous)

This makes it impossible to have a single cyclone geometry to effectively deal with all cases

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UNDERSTANDING HOW CYCLONES WORK

Very different particle size distributions occur in any process (Ex: Spray Drying)
UNDERSTANDING HOW CYCLONES WORK

Effect of residence time inside a cyclone

REF: $\rho_p=1450$ kg.m$^{-3}$
$D_{max} = 6$ µm
$t_{max} = 10$ ms
$C_{in} = 700$ mg.m$^{-3}$
UNDERSTANDING HOW CYCLONES WORK

Effect of maximum collision (target) diameter

[Graph showing the effect of maximum collision (target) diameter on efficiency, with lines for different diameters (Initial, 4 μm, 6 μm, 8 μm).]
UNDERSTANDING HOW CYCLONES WORK

Effect of inlet concentration

- Initial
- 7 mg/m³
- 700 mg/m³
- 70 g/m³

ML (not sensitive to C_in)
Predicting particle agglomeration in cyclones (PACyc)

Fluid Velocity

\[ t = t + \Delta t \]

Particle Trajectory

Collision?

Agglomerated?

\[ U_{p1} + U_{p2} \]

\[ D_{new} & U_{new} \]
UNDERSTANDING HOW CYCLONES WORK

Developing the best theory for cyclone collection

Grade Efficiency Curves for two experiments (theoretical and experimental results)
UNDERSTANDING HOW CYCLONES WORK

Good agreement with experimental Hurricane HR data

ML (1988)

PACyc (2010)

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• We have extended the ML (1988) and Ho and Sommerfeld (2002) models to predict fine particle clustering in turbulent cyclone flows

• Good agreement between experimentally observed grade-efficiency curves and those from our model

• Excellent agreement between predicted and experimental global collection efficiency

• There is now a theoretical framework on which to base our hypothesis, viz. that clustering inside the cyclone may be responsible for the very high collection of fine particles
UNDERSTANDING HOW CYCLONES WORK
Designing the best cyclone system for each application

Empirical development

2 level factorial experiment → 128 prototypes
4 level factorial experiment → 16384 prototypes

Numerical optimization

Able to generate millions of “prototypes”

Cleaned gas
Dusty gas
8 dimensions
4 axial
4 radial

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Thanks to the PACyc Model it is possible to simulate millions of virtual prototypes resorting to numerical optimization. Different industrial cases have different needs for which the optimization functions to incorporate in the PACyc model may be as complex as minimizing cost or space, subject to a minimum efficiency result.

The cyclone families above are the result of very different client demands ACS has come across until now.
OPTIMIZING CYCLONE EFFICIENCY
Designing the best cyclone system for each application

Alternative Cyclone Solutions – Real Case Analysis: Spray Drying of Demineralized Powder

<table>
<thead>
<tr>
<th>Powder</th>
<th>Demineralized Whey*</th>
<th>Gas Temperature</th>
<th>90°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSD Median (Volume Based)</td>
<td>20µm</td>
<td>Flow Rate</td>
<td>100 000m³/h</td>
</tr>
<tr>
<td>Inlet Concentration</td>
<td>154mg/Nm³ dry</td>
<td>Moisture Content in the Flue Gas</td>
<td>7% (v/v)</td>
</tr>
</tbody>
</table>

*Escaping the process cyclones of the spray dryer

Global Efficiency (%):  

- **MK**: 96%  
- **EX**: 95%  
- **RE**: 92%  
- **RX**: 87%  
- **HR**: 81%  
- **TX**: 72%

Emissions (mg/Nm³):  

- **MK**: 7  
- **EX**: 9  
- **RE**: 13  
- **RX**: 21  
- **HR**: 29  
- **TX**: 42

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## OPTIMIZING CYCLONE EFFICIENCY

Designing the best cyclone system for each application

<table>
<thead>
<tr>
<th>Cyclones needed (⌀2900mm)</th>
<th>System size</th>
<th>Objectives / Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>MK</td>
<td>100%</td>
<td>The agglomerator cyclone – Maximum agglomeration. Most efficient cyclones</td>
</tr>
<tr>
<td>EX</td>
<td>65%</td>
<td>Ultra high efficiency with agglomeration to compete with Bag Filters.</td>
</tr>
<tr>
<td>RE</td>
<td>53%</td>
<td>Final stage cyclones with agglomeration for strict emission limits</td>
</tr>
<tr>
<td>RX</td>
<td>33%</td>
<td>Very high efficiency cyclones for process and end stage applications.</td>
</tr>
<tr>
<td>HR</td>
<td>23%</td>
<td>High efficiency cyclones for process and end stage applications</td>
</tr>
<tr>
<td>TX</td>
<td>15%</td>
<td>Good efficiency process cyclones to increase powder yield</td>
</tr>
</tbody>
</table>

www.advancedcyclonesystems.com
Residual emissions (mg/Nm$^3$) at the stack from slide 17. Example: Spray drying of demineralized whey powder

Designing the best cyclone for the client
Selecting between mechanical or electrostatic recirculation to decrease global emissions in 50 or 75%, respectively
Adding unique cyclonic recirculation systems

See Hurricane & ReCyclone in 3D action

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ACS’ cyclone designs substantially decrease global emissions

Efficiency comparison between ACS alternatives, a Bag Filter and a competitor cyclone.

Quimigal | Portugal | 2009
ReCyclone EH to recover sulphanilic acid

Grade and Global Efficiency:

Global efficiency:
- Bag Filter 99.0%
- Competitor HE cyclone 95.0%
- Hurricane 98.5%
- ReCyclone® EH 99.8%
- ReCyclone® MH 99.6%

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AC Systems are generally supplied in pre-assembled modules for easier installation.

ACS systems are mostly supplied in groups of cyclones (batteries) and recirculators, disposed vertically instead of horizontally, to minimize layout space. Usually, supply includes the support structure, insulation, ductwork, recirculation fan and control board.
HOW WE COMPARE WITH OTHER TECHNOLOGIES
ACS CYCLONES ARE OPTIMUM FOR EMISSIONS CONTROL

Residual emissions comparison between ACS products

<table>
<thead>
<tr>
<th>Comparison of fine powder secondary collectors (placed after process cyclones in spray dryers)</th>
<th>Wet Venturi Scrubbers</th>
<th>&quot;CIPable&quot; Bag Filter</th>
<th>Competitor Hight Efficiency Cyclone</th>
<th>Hurricane cyclones: HR, RX, RE, EX, MK</th>
<th>ReCyclone® MH systems</th>
<th>ReCyclone® EH systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency (%)</td>
<td>85 to 95</td>
<td>99+</td>
<td>60 to 70</td>
<td>81 to 95</td>
<td>88 to 96</td>
<td>93 to 97</td>
</tr>
<tr>
<td>Emissions: (depending on system configuration)</td>
<td>10 to 25</td>
<td>&lt;10</td>
<td>45 to 60</td>
<td>9 to 25</td>
<td>7 to 18</td>
<td>4 to 11</td>
</tr>
<tr>
<td>Quality of separated product</td>
<td>Waste</td>
<td>Second grade</td>
<td>First grade</td>
<td>First grade</td>
<td>First grade</td>
<td>Waste, if organic</td>
</tr>
<tr>
<td>Contamination risk (sanitary conditions)</td>
<td>Very high</td>
<td>Considerable</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Minimal</td>
</tr>
<tr>
<td>Cleaning perfection with CIP</td>
<td>Bad</td>
<td>Reasonable</td>
<td>Very Good</td>
<td>Very Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Investment costs</td>
<td>Low</td>
<td>Very high</td>
<td>Low</td>
<td>Low/Reasonable</td>
<td>Reasonable</td>
<td>High</td>
</tr>
<tr>
<td>Maintenance and operating costs</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Performance of different equipments for the collection of demineralized whey powder
Median particle size in Volume (MVD) = 20μm, \( r(\text{kg/m}^3) = 1000 \) | Inlet concentration: 154mg/Nm³

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FIRST STAGE OR SECOND STAGE CYCLONES?

Value of powder lost and emissions

E M I S S I O N  L I M I T

First Stage or Second Stage Cyclones?

Value of powder lost to atmosphere or bag house

Severity of emissions from 1st stage cyclones

- Use regular 1st stage cyclone
- Use high efficiency 1st stage cyclone plus Bag House
- Use high efficiency 2nd stage cyclone plus bag house
- Use regular cyclone plus Bag House

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Hurricane HR

for the recovery of food ingredients from MSD spray dryer

- **Technology**
  Hurricane HR

- **Application**
  Milk proteins recovery after spray dryer

- **Dimension**
  92,140 am³/h at 65°C

- **Load into Cyclone System**
  ≈16,900 mg/Nm³ dry

- **Guaranteed Efficiency**
  98.9 - 99.3%

- **Increased Recovered Powder**
  320 ton/year

- **Alternative technology**
  Competitor High Efficiency cyclone
Case Study

Hovione | Portugal | 2010
Hurricane HR
for Active Pharmaceutical Ingredients
powder recovery

- **Technology**
  Hurricane HR

- **Application**
  API Powder recovery after Industrial Scale Spray Drying.

- **Dimension**
  1.450 kg/h N2 + 40 kg/h H20

- **Guaranteed Efficiency**
  96 - 98 %

- **Alternative technology**
  Competitor High Efficiency cyclone
Technology
Hurricane HR

Application
API Powder recovery after Industrial Scale Spray Drying.

Dimension
1.450 kg/h N2 + 40 kg/h H20

Load into Cyclone
500 mg/Nm³

Guaranteed Efficiency
96 - 98 %

Alternative technology
Competitor High Efficiency cyclone
• Technology
  Recyclone® MH

• Application
  Emission control and product recovery of organic fertilizer dust after “tunnel” dryer.

• Dimension
  108,000 m³/h at 40°C

• Load into Cyclone System
  ≈1,580 mg/Nm³

• Guaranteed Emissions
  100 mg/Nm³

• Measured Emissions in 2013
  < 50 mg/Nm³

• Alternative technology
  Wet Venturi Scrubber
Hurricane
Cyclones to displace the investment in a bag filter while recovering more milk powder

- Technology
  Hurricane

- Application
  Milk powder recovery after spray dryer existing cyclones

- Dimension
  31 100m³/h at 160°C

- Load into Cyclone System
  ≈345mg/Nm³

- Particle Size Distribution
  - D10: 3 microns; D50: 10.5 microns; D90: 35 microns

- Guaranteed Efficiency
  >85%

- Guaranteed Emissions
  < 75mg/Nm³
  Measured in 2016: 25mg/Nm³

- Alternative technology
  Bag Filter (BF)
Hurricane
For fat powder pneumatic transport with very high efficiency

- **Technology**
  Hurricane

- **Application**
  Fat powder pneumatic transport @ 0 °C

- **Dimension**
  4 080m³/h at 180°C

- **Load into Cyclone System**
  ≈ 237 0000mg/Nm³

- **Particle Size Distribution**
  - D10: 30 microns; D50: 65 microns; D90: 105 microns

- **Guaranteed Efficiency**
  >99.94%

- **Alternative technology**
  Competitor High Efficiency cyclone
Albarracin | Spain | 2016
Hurricane HR

to recover paprika powder from 3 milling lines

• **Technology**
  Hurricane HR

• **Application**
  Recover paprika powder

• **Dimension**
  11 010m³/h at 47.5°C

• **Load into Cyclone System**
  ≈272mg/Nm³

• **Guaranteed Efficiency**
  97,4 – 97,9 %

• **Guaranteed Emissions**
  <150mg/Nm³

• **Alternative technology**
  Bag Filter (BF)
Hurricane HR

to separate iron oxide particulates from compressed air

- **Technology**
  Hurricane HR

- **Application**
  Capture of iron oxide particles

- **Dimension**
  15 233Am³/h at 40°C

- **Load into Cyclone System**
  10mg/Nm³

- **Guaranteed Emissions**
  <7mg/Nm³

- **Guaranteed Efficiency**
  88.5 – 89.9 %

- **Alternative technology**
  Bag Filter

- **Alternative Cyclone**
  More expensive for the same efficiency
Hurricane HR
Waste particles capture from the combined flow of a deduster and a tablet press

- **Technology**
  Hurricane HR

- **Application**
  Waste particles from a pharmaceutical tablet press

- **Dimension**
  416Am³/h at 20°C

- **Load into Cyclone System**
  ≈1 250mg/Nm³

- **Guaranteed Emissions**
  <20mg/Nm³

- **Guaranteed Efficiency**
  99,38 – 99,64 %

- **Alternative technology**
  Electrostatic Precipitator (ESP), 70% more expensive
Hurricane HRC
Product recovery of dry yeast particles

- **Technology**
  Hurricane HRC

- **Application**
  Dry yeast particles recovery from an air flow

- **Dimension**
  398Am³/h at 45°C

- **Load into Cyclone System**
  1 885 035mg/Nm³

- **Guaranteed Efficiency**
  99,64 – 99,67 %

- **Alternative technology**
  Bag Filter
Ipsen | France | 2015

Hurricane HR
to capture a patent active pharmaceutical product

• **Technology**
  ReCyclone® MH

• **Application**
  Capture a patent active pharmaceutical product

• **Dimension**
  113Am³/h at -85°C

• **Load into Cyclone System**
  ≈ 8 023mg/Nm³

• **Guaranteed Emissions**
  <100 mg/Nm³

• **Efficiency**
  Rods - 98.6 – 98.7 %
  Pellets 100 %

• **Alternative technology**
  Competitor High Efficiency cyclone
Corrugados Getafe | Spain | 2011

Hurricane HR
Recovery of white slag dust after pneumatic transport

- **Technology**
  Hurricane HR

- **Application**
  White slag transport

- **Dimension**
  158 500m³/h at 165°C

- **Load into Cyclone System**
  ≈ 375mg/Nm³

- **Guaranteed Emissions**
  <15mg/Nm³

- **Guaranteed Efficiency**
  97%
PERMANENTLY INNOVATING OUR SYSTEMS
INDUSTRIAL EXAMPLES
ACS HAS PROVEN APPLICABILITY IN A BROAD VARIETY OF APPLICATIONS

**EMISSION CONTROL**

Environmental Improvement

- Biomass and Coal Combustion
- Steel and Ferroalloys
- Pyrolysis, Incineration and Gasification
- Air Caption and Deducing
- Biomass Dryers
- Fuel Oil Combustion
- Clinker Cooler and Pre-Heater Dedusting
- Calcination Processes
- High Temperature Separation Processes for Energy Recovery

**POWDER RECOVERY**

Serious Economic Added Value

- Pharmaceutical Ingredients
- Food Ingredients
- Mineral Processing
- Chemicals
- Nanoparticles
- Fertilizers
- Milling and Drying Processes

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FILTRATION AND SEPARATION TECHNOLOGIES

Two main market needs

• Cyclones are widely used in many industries

• Low cyclone efficiency results in high product losses and high emissions in many plants
  
  • Efficiency increase implies a new approach to cyclone design - PACyc

  • Customized numerically optimized cyclones (Hurricane) reduce losses up to 90%

• Hurricane & ReCyclone® systems maintain cyclones’ advantages while improving efficiency dramatically, reaching near bag filter performance in several applications, while enabling thermal energy recovery.

• Wide application range with unquestionable advantages over alternative dedusters, ensuring emission limits compliance by small to medium companies

• Numerous successful case studies and environmental innovation awards

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